Relational aspects, between Gravity and the Quantum

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BRCP

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Relationality?

General Relativity: diffeomorphism invariance / general covariance

Quantum Mechanics: relative state / relational interpretation

Relationality?

General Relativity: diffeomorphism invariance / general covariance

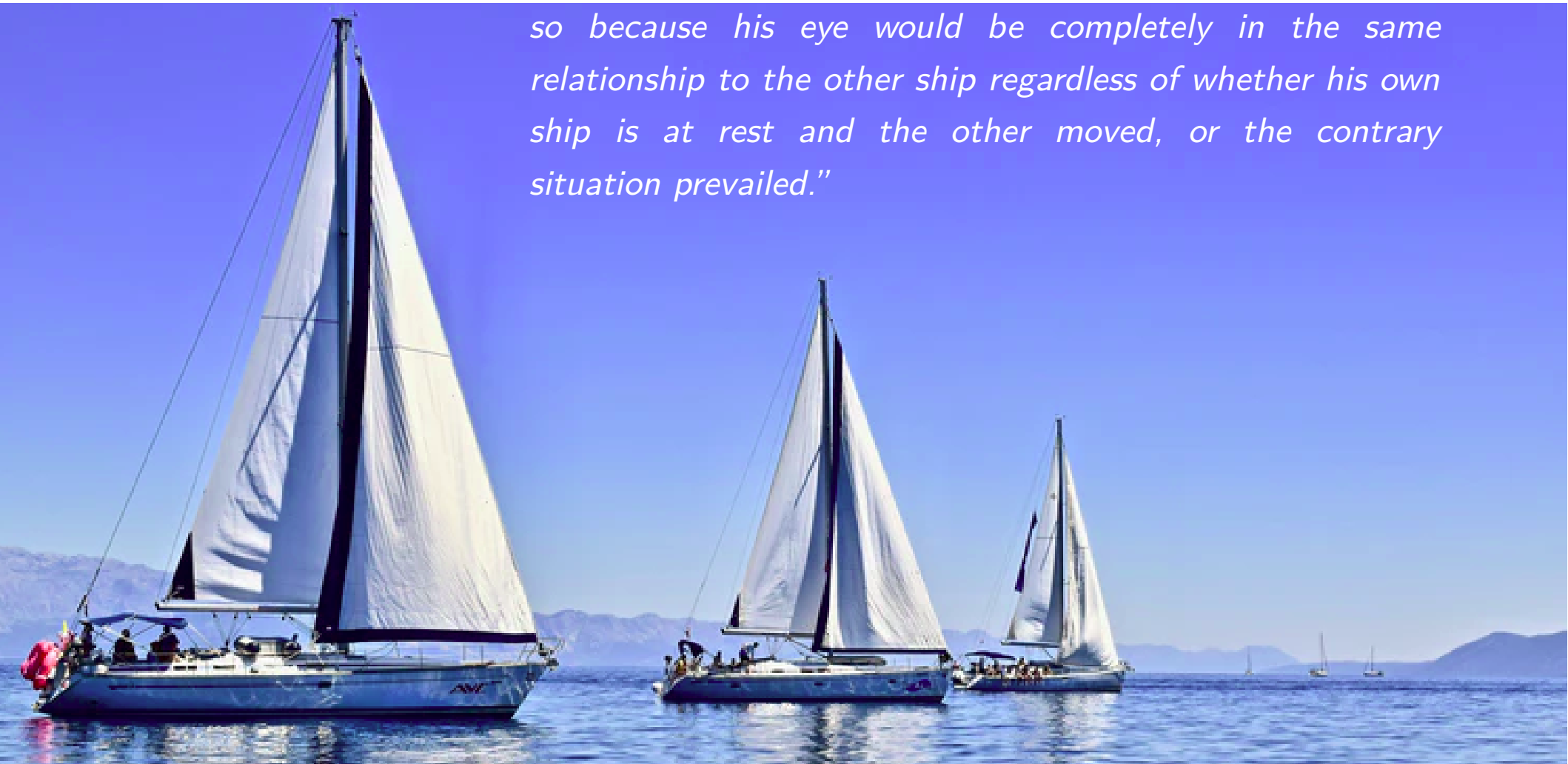
Quantum Mechanics: relative state / relational interpretation

Are these the same?

Quantum Gravity?

Classical mechanics

"If anyone is moved in a ship and he imagines that he is at rest, then, should he see another ship which is truly at rest, it will appear to him that the other ship is moved. This is so because his eye would be completely in the same relationship to the other ship regardless of whether his own ship is at rest and the other moved, or the contrary situation prevailed."



Classical mechanics

Kinematic relativity

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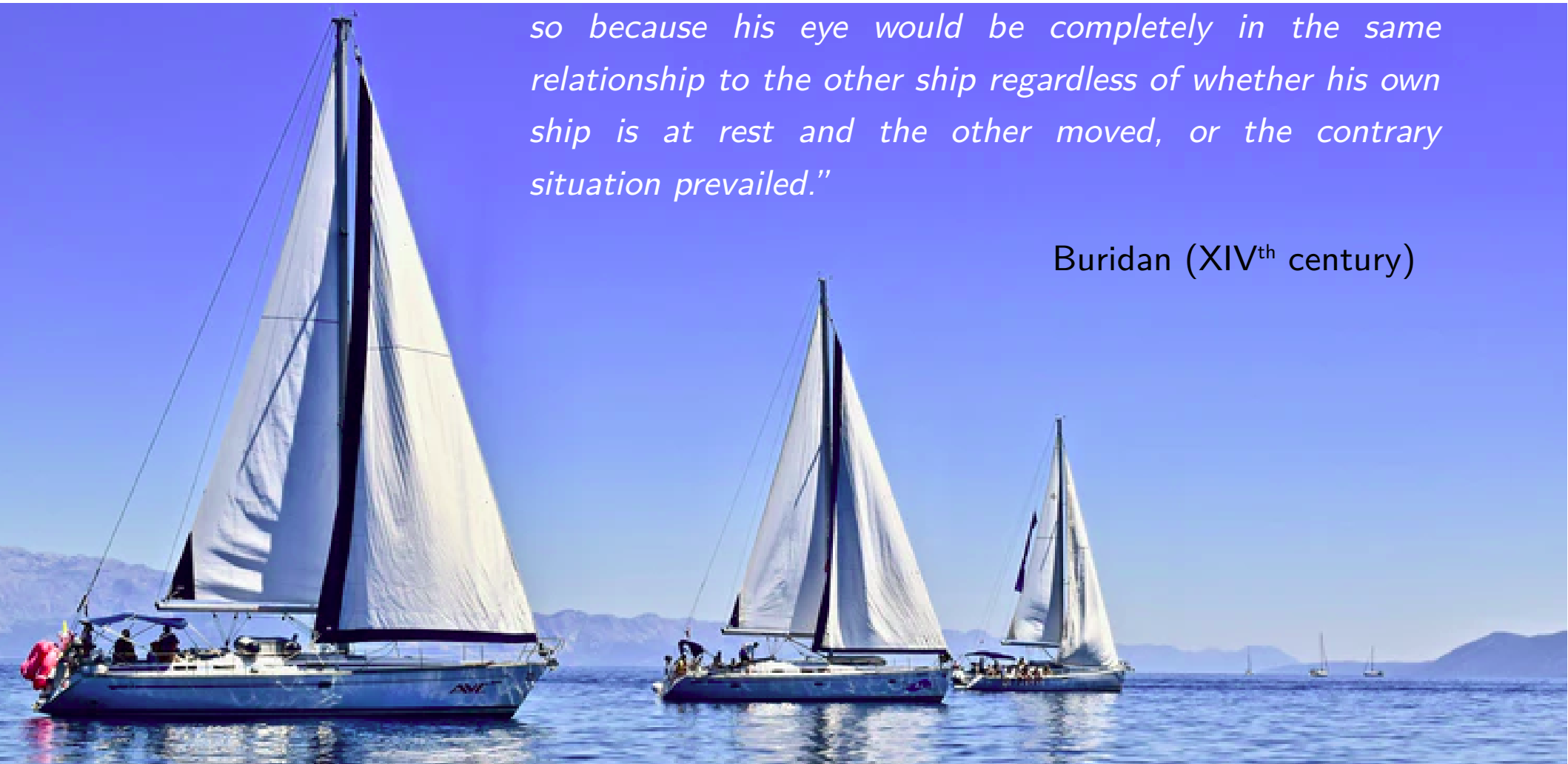
Buridan (XIVth century)



Classical mechanics

Fundamental problem of motion (Julian Barbour): *if all motion is relative and everything in the universe is in motion, how can one ever set up a determinate theory of motion?*

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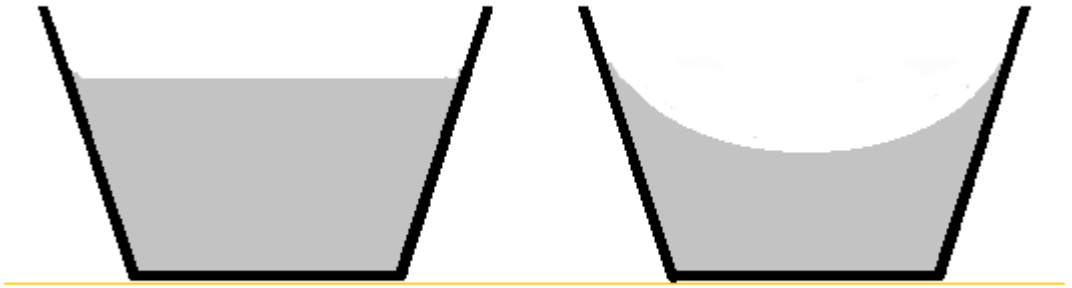
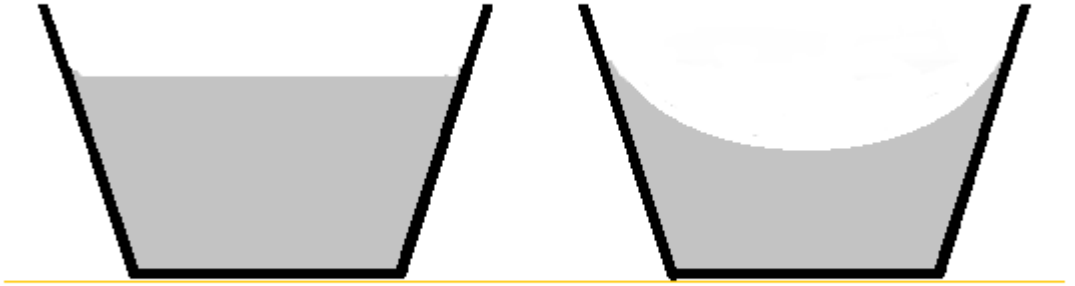


Newton's bucket

Classical mechanics

Fundamental problem of motion (Julian Barbour): *if all motion is relative and everything in the universe is in motion, how can one ever set up a determinate theory of motion?*

Absolute space



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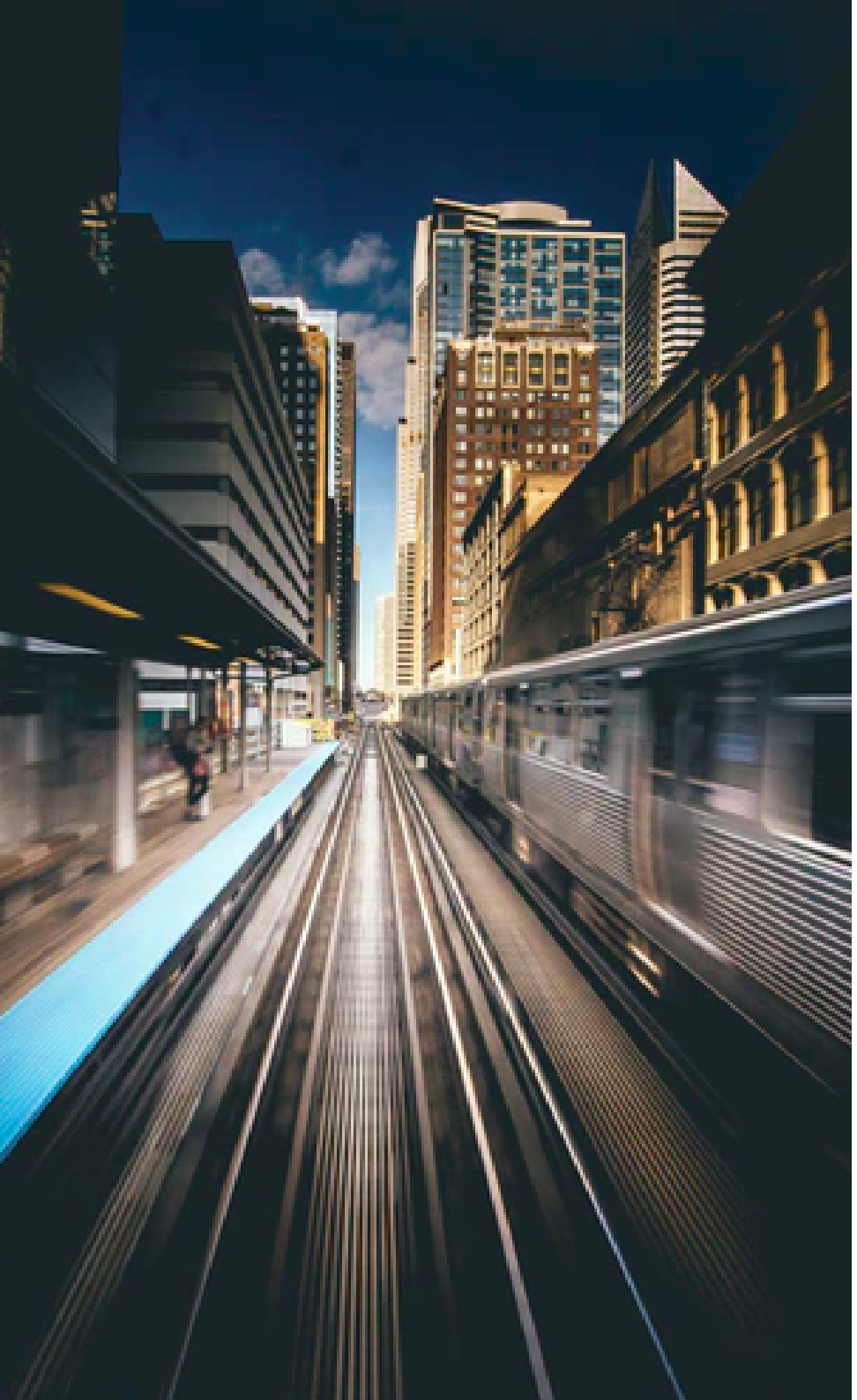
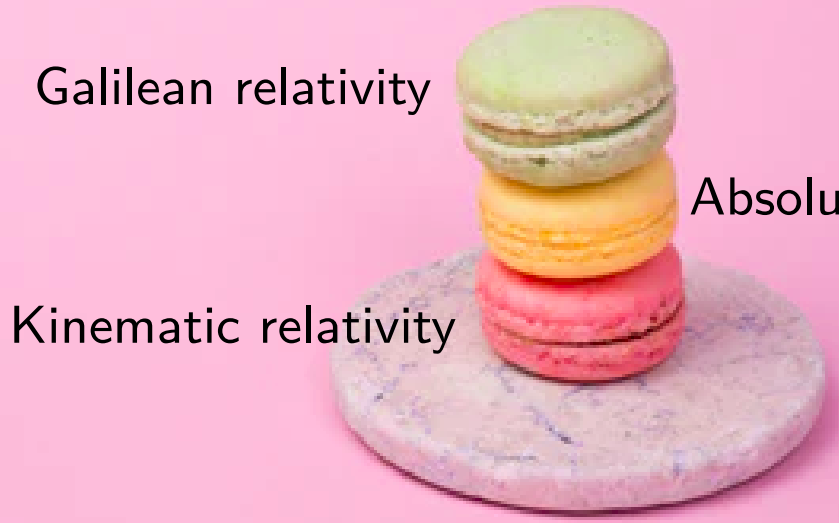


Classical mechanics

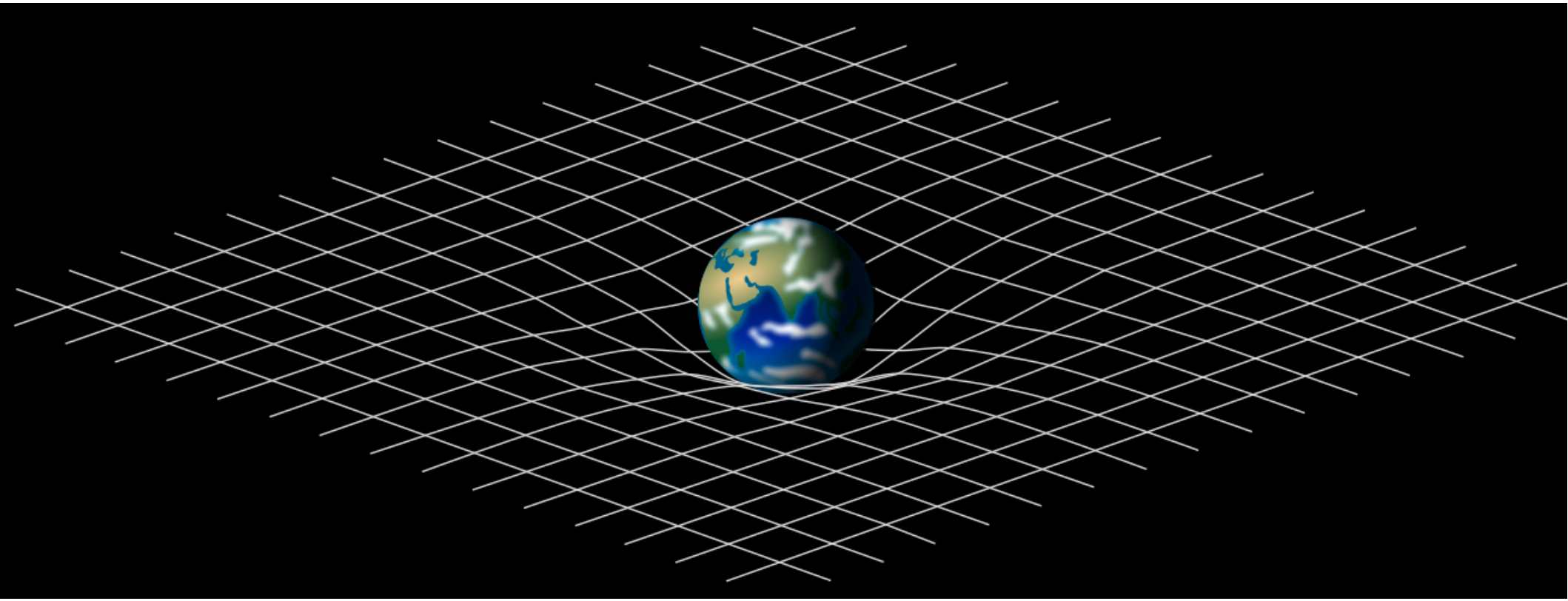
Galilean relativity

'The motions of bodies included in a given space are the same among themselves, whether that space is at rest, or moves uniformly forwards in a right line without any circular motion'

Classical mechanics



General Relativity

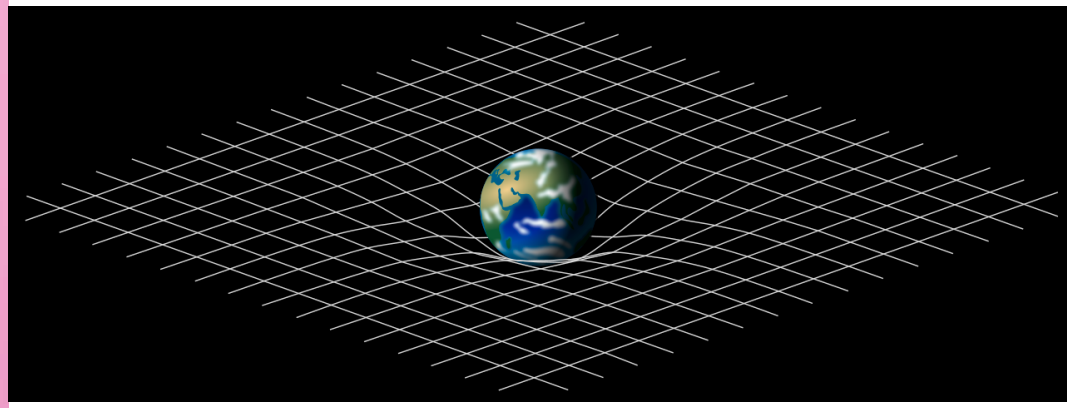


General Relativity

Diffeomorphism invariance

?

General covariance



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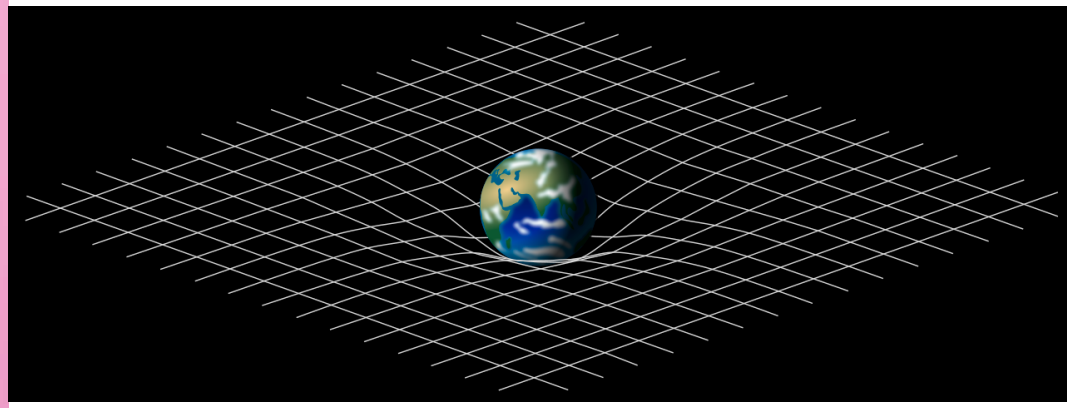


Hole argument $\rightarrow$ Spacetime points are not points of the manifold

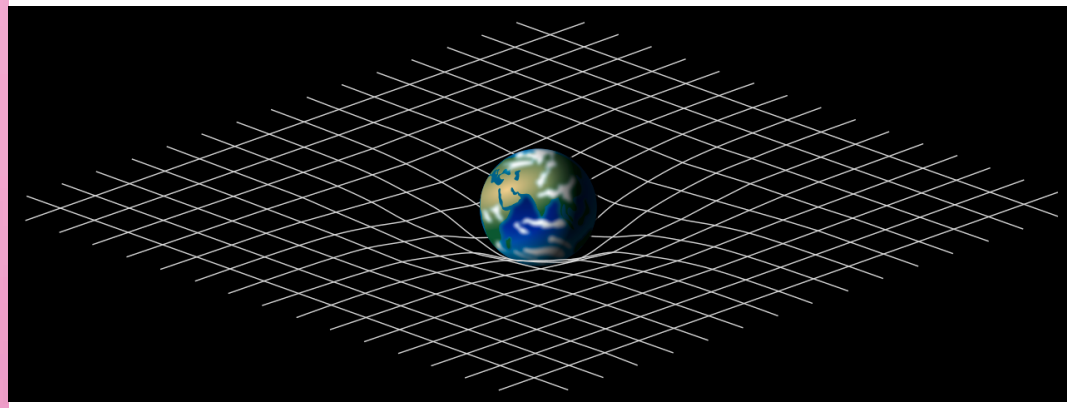
General Relativity

$$g_{\mu\nu}(x)$$

Diffeomorphism invariance

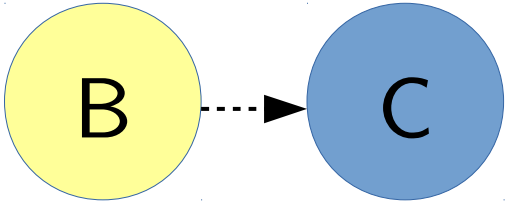
Equivalence class

General covariance



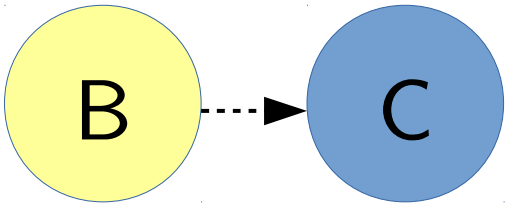
Hole argument $\rightarrow$ Spacetime points are not points of the manifold

Quantum Mechanics



1957 H. Everett, ‘Relative State’ formulation of Quantum Mechanics

Quantum Mechanics



$$\rho_C^0$$

$$\rho_C^t = P\,\rho_C^0\,P^{-1}$$

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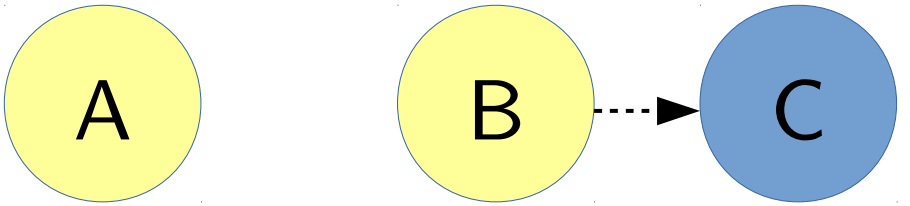
Quantum Mechanics



$$\rho_C^0 \qquad \rho_C^0$$

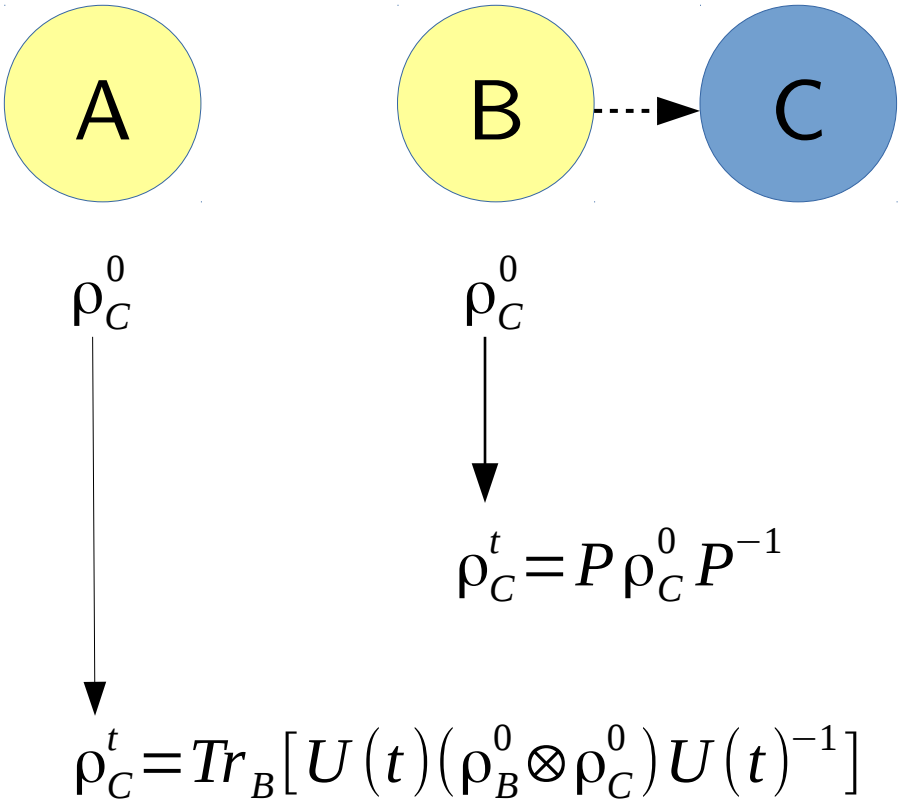
$$\rho_C^t = P\,\rho_C^0\,P^{-1}$$

$$\rho_C^t = Tr_B\left[U(t)\left(\rho_B^0 \otimes \rho_C^0\right)U(t)^{-1}\right]$$

1957 H. Everett, 'Relative State' formulation of Quantum Mechanics

Quantum Mechanics

Relational Interpretation



1957 H. Everett, 'Relative State' formulation of Quantum Mechanics

1995 C. Rovelli, Relational Quantum Mechanics

Quantum Mechanics

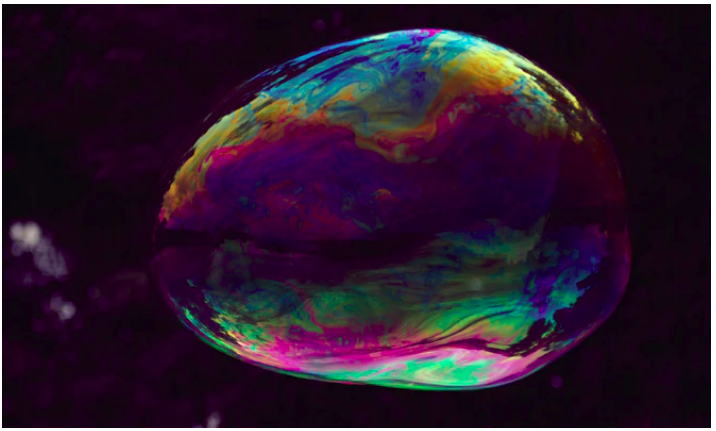
Left-handed or right-handed cup?

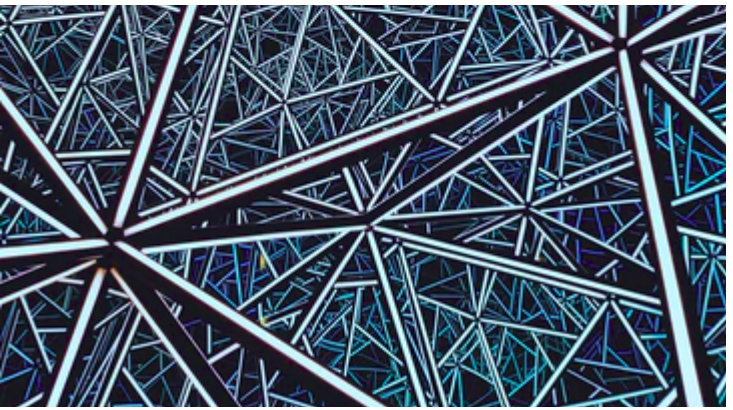
Quantum Mechanics

Left-handed or right-handed cup?

Red or Green quark?

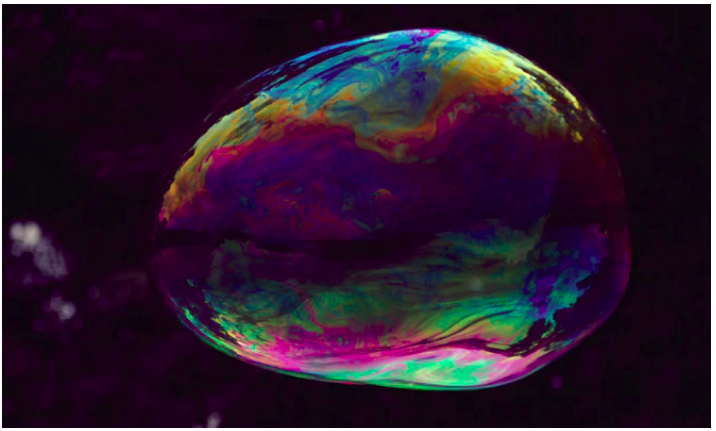
Quantum Gravity





Quantum Gravity

2009 R. Oeckl, General boundary quantum field theory



3d surface of spacetime

Quantum Gravity

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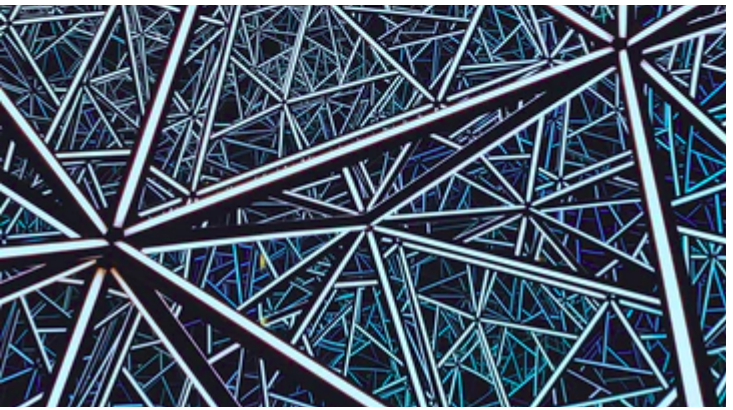
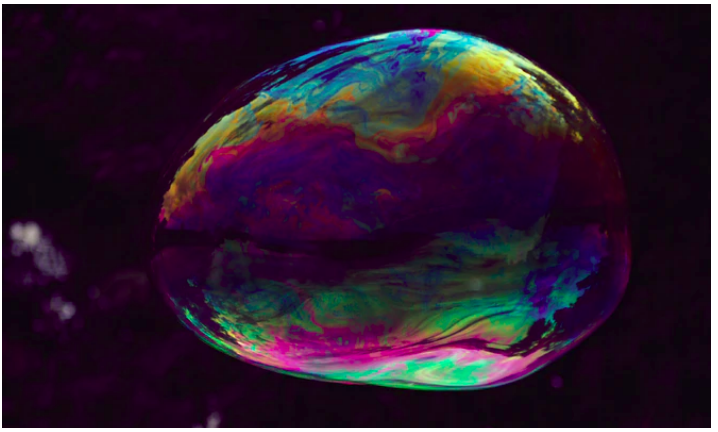
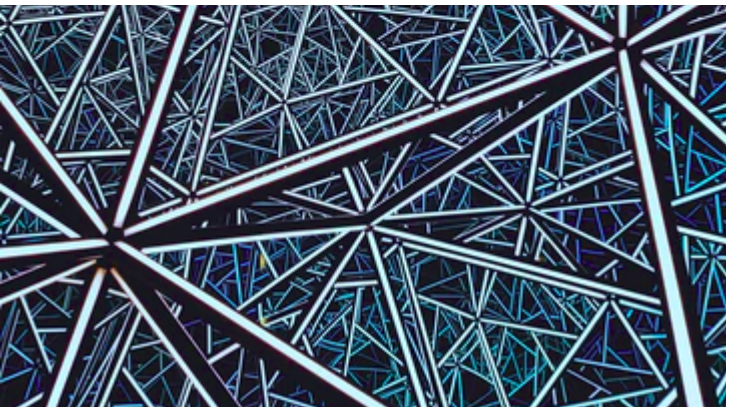




3d surface of spacetime

Spin-network state Ψ



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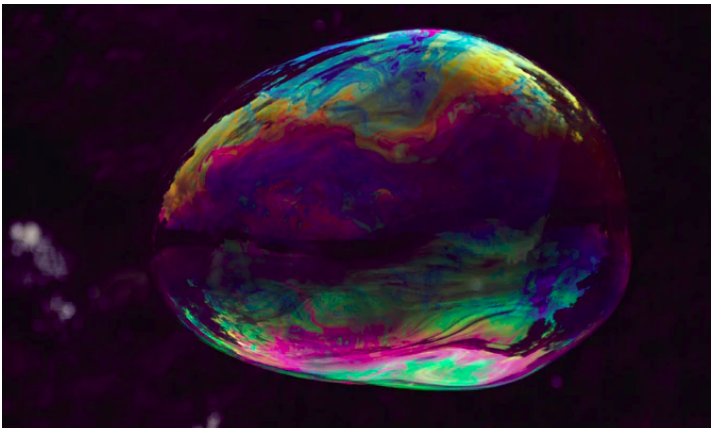

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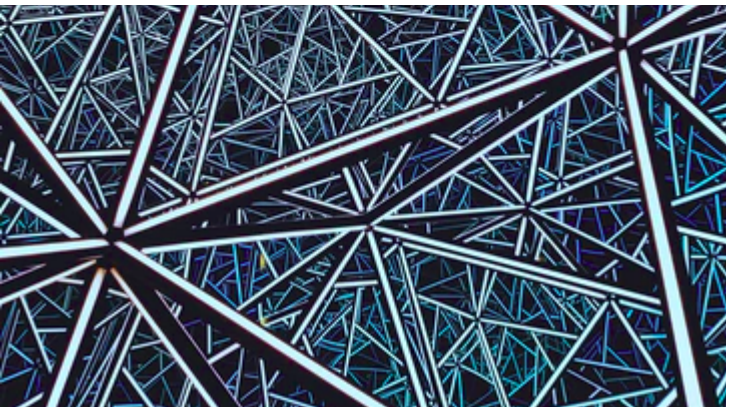
Spin-network state Ψ

Spin-network amplitude



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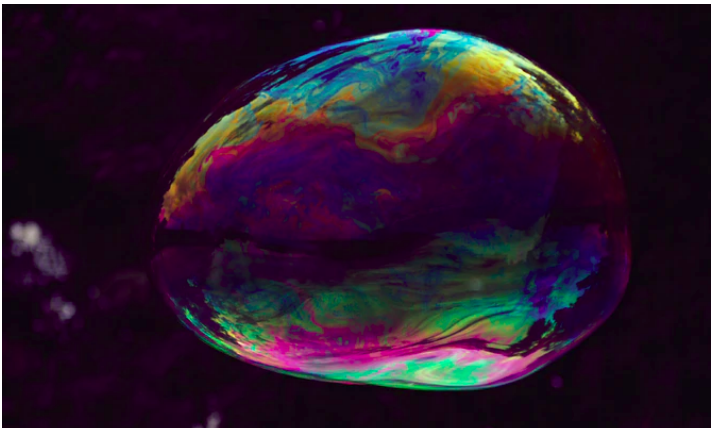

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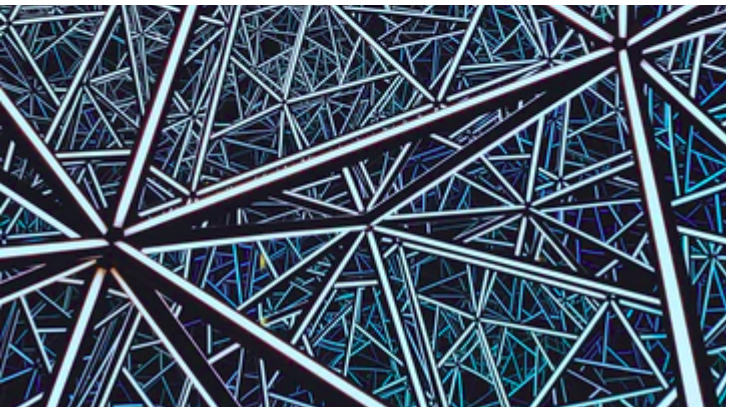
Spin-network state Ψ

Spin-network amplitude

$$\rho(\Psi) \stackrel{\text{def}}{=} \sum_{\sigma} \sum_{j} \sum_{\iota} \mathcal{A}(\sigma, j, \iota)$$



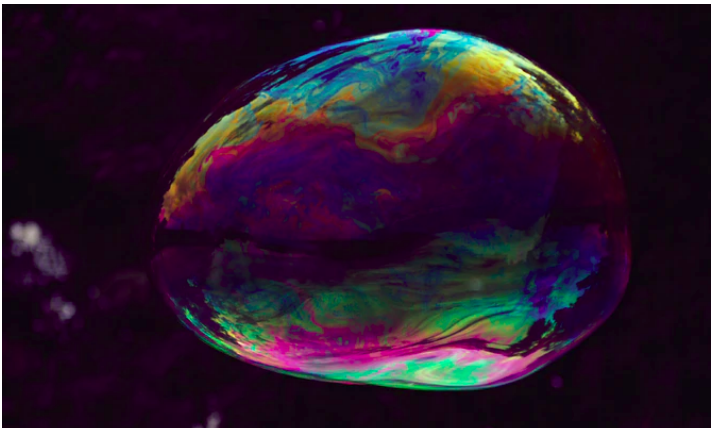
Spin-foam amplitude

$$\mathcal{A}(\kappa, j, \iota) = \left(\prod_{f \in \mathcal{F}} (2j_f + 1) \right) \left(\prod_{e \in \mathcal{E}} (2\iota_e + 1) \right) \left(\prod_{v \in \mathcal{V}} A_v(j, \iota) \right)$$

$$A_v(j, \iota) = \left(P_{SL_2(\mathbb{C})} Y_\gamma \Psi_{(\Gamma, j, \iota)} \right) (\mathbb{1})$$

2009 R. Oeckl, General boundary quantum field theory

Quantum Gravity



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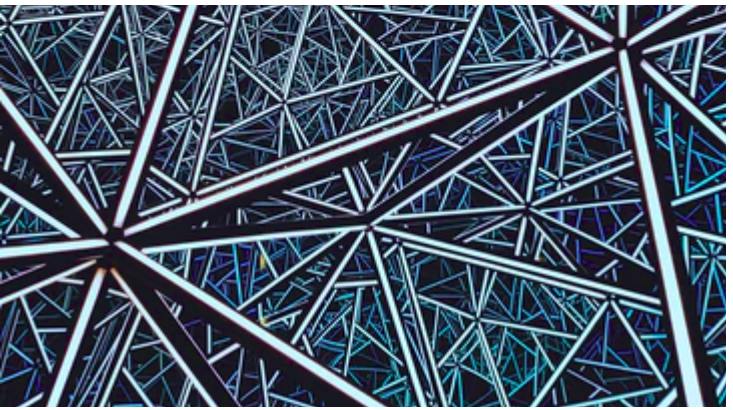

Spin-foam amplitude

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Probability between states of knowledge:

$$P(\mathcal{A}|\mathcal{S}) = \frac{\sum_{i\in I} |\rho(\xi_i)|^2}{\sum_{j\in J} |\rho(\zeta_j)|^2}$$

$$\rho(\Psi) \stackrel{\text{def}}{=} \sum_{\sigma} \sum_{j} \sum_{\iota} \mathcal{A}(\sigma, j, \iota)$$

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Conclusion

Many relational features in:

1. Classical mechanics
2. General Relativity
3. Quantum Mechanics
4. Quantum Gravity

Other references:

1989 J. Earman, World Enough and Space-time

1992 J. Barbour, The Discovery of Dynamics

1999 C. Rovelli, 'Localisation' in QFT

Photos:

unsplash.com